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13. ABSTRACT (Maximum 200 words)

In order to investigate the strain-rate dependence of the mechanical behavior over a wide range of strain rates, a small version of the Kolsky Bar, called the Desktop Kolsky Bar, has been developed for testing small samples. The results of the experimental and numerical examinations show that this technique can be utilized for measuring the high-rate behavior at strain rates from $\sim 10^{+3}$ s^{-1} up to $\sim 5 \times 10^{+4}$ s^{-1}. The technique can bridge the capabilities of the conventional Kolsky bar and pressure-shear plate impact techniques, and thus improve our understanding of material behavior at high rates.
Our experimental work has all been on the aluminum alloy 6061-T651. While we have been able to obtain both desktop Kolsky bar data at 5×10^4 s^{-1} and pressure-shear plate impact data on this material, we have not as yet been able to obtain overlapping data. The lowest strain rate that we have achieved in the pressure-shear experiment is 8×10^4 s^{-1}, rather than the 5×10^4 s^{-1} that needed for direct comparison.

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Final Progress Report: ARO STIR Award DAAD190110536

Introduction

This technical report describes the work performed under ARO Award DAAD190110536 to Professor K.T. Ramesh and the Johns Hopkins University. This STIR award was used to fund research within the Laboratory for Impact Dynamics and Rheology by students working under the supervision of Professor K.T. Ramesh.

Statement of Problem Studied

Extremely high strain rates are routinely developed during impact events. The development of improved armor and anti-armor is therefore predicated on an understanding of high-rate phenomena. In particular, it is critical that we have accurate experimental measurements of the response of materials to such extreme rates of deformation. Such experimental data can then be used to construct models for material behavior which can be incorporated within computational simulations of the impact event. The strain rate range of interest is typically $10^2 - 10^6\ s^{-1}$. Unfortunately, there is no approach right now for accessing the critical strain rate range of $10^4 - 10^5\ s^{-1}$. Kolsky bars reach rates up to $8x10^3\ s^{-1}$, and high-strain-rate pressure-shear plate impact goes down as low as $5x10^4\ s^{-1}$, but there is no overlapping technique at present. This project was intended to provide, for the first time, experimental data on a single material using two distinct experimental techniques (high-strain-rate pressure-shear plate impact and the compression Kolsky bar or split-Hopkinson pressure bar) with significant overlap over the strain rate range of $10^4 - 10^5\ s^{-1}$.

Summary of Most Important Results

We have developed a modification of the traditional compression Kolsky bar or split-Hopkinson pressure bar experimental technique to provide significantly enhanced capabilities. The improved system, called the Desktop Kolsky Bar (DKB) because it is essentially a desktop system, is easy to run and easy to build. We have completed a careful experimental examination of the DKB to validate all of its capabilities, and to address all of the typical questions that arise in very-high-strain-rate testing of this type (that is, we have validated the technique). The DKB is able to address material properties at the strain rates of interest for a number of dynamic applications, including armor penetration and high-speed machining. This technique can be utilized for measuring the high-rate behavior at strain rates from ~1,000 to 50,000 s^{-1}, bridging the capabilities of the conventional Kolsky bar and pressure-shear plate impact techniques, and thus improving our understanding of material behavior at high rates. The key features of the DKB are the following:

- The technique is simple, and the technology is relatively cheap. The entire system can be designed to fit on a desktop.
- Very high strain rates (up to $5 \times 10^{+4}\ s^{-1}$) can be attained, while retaining the ability to study materials at strain rates as low as $1.0 \times 10^{+3}\ s^{-1}$.

- The desired high-strain-rate can be achieved at low accumulated strains, and the total strain developed can be controlled very effectively.
- Recovery tests at very high strain rates are easily implemented.
- Inertial errors in stress measurement are significantly reduced.
- A good state of stress equilibrium is quickly reached in a small specimen at a very-high-strain-rate DKB experiment.

We have also performed numerical simulations for a further examination of the very-high-strain-rate Desktop Kolsky Bar experiment, and can draw the following further conclusions from the simulations:

- A rapid equilibration of stress in a small sample can be achieved even at a very high strain rate of 3-5 $\times 10^{+4}$ s^{-1}.
- Interfacial friction has strong influences on the stress-strain response and stress/strain distribution in a sample. Therefore, effective lubrication remains critical. The Desktop Kolsky Bar makes it possible to reach a very high strain rate in a small sample with a high *l/d* ratio to minimize the influence of friction.
- The stress-strain response of a small sample from a very-high-strain-rate Desktop Kolsky Bar experiment can accurately represent the stress-strain relation of the specimen material.
- It is now possible to rigorously evaluate materials that are only available in limited sizes, such as nanostructured materials, amorphous metals, single crystals, and the sheet metals used in the automobile and aircraft industries.

Our experimental work has all been on the aluminum alloy 6061-T651. While we have been able to obtain both desktop Kolsky bar data at 5×10^4 s^{-1} and pressure-shear plate impact data on this material, we have not as yet been able to obtain overlapping data. The lowest strain rate that we have achieved in the pressure-shear experiment is 8×10^4 s^{-1}, rather than the 5×10^4 s^{-1} that needed for direct comparison. The low end of the plate impact experiment range requires some additional experiments, and Mr. Zhang is proceeding to try to accomplish these very exacting tests at the lower limit of the range.

Publications resulting from the Award:

1. Jia, D. & Ramesh, K.T., "A Rigorous Assessment of the Benefits of Miniaturization in the Kolsky Bar System, Part I: Experimental Investigations," under preparation.
2. Jia, D. & Ramesh, K.T., "A Rigorous Assessment of the Benefits of Miniaturization in the Kolsky Bar System, Part I: Numerical Simulations," under preparation.

Students Supported

D. Jia, Ph.D., June 2001.
H. Zhang, doctoral student.

Report of Inventions

None.